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Influence of freeze–thaw cycles on fracture parameters values of lightweight concrete

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Abstract

Freezing and thawing resistance is very important characteristic also in the case of lightweight concrete. The paper deals with the influence of periodic freeze–thaw cycles on lightweight concrete fracture parameters values. Sets of lightweight concrete specimens (prismatic shape) are cyclically frozen in range from +20°C to -20°C. The main aim of the experimental part is to determine and compare the mechanical/fracture parameter values of a composite both frozen and non-frozen. The non-frozen specimens are air/water-cured. A three-point bending test of beams with a central edge notch is used in order to determine the fracture parameters values. It particularly covers effective fracture toughness and fracture energy. The notch is cut after 200 freezing cycles before fracture tests. The other parameters values – compressive and splitting tensile strength on the specimen fragments – are determined.

Keywords: Lightweight concrete; freeze–thaw test; fracture parameters; splitting tensile strength; durability

1. Introduction

Lightweight aggregate concrete (LWAC) can be classified as a special high performance concrete which contains porous aggregate with low bulk density. LWAC are characterized by specific distribution and content of air voids in matrix as well as in the aggregate particles and the bond between aggregate and matrix is, among others, influenced by the actual degree of the aggregate particles saturation. The main disadvantage of these concretes is high sensitivity to the curing conditions which can significantly influence the initiation and propagation of cracks. This fact leads to the changes of physico-mechanical, fracture and durability parameters. There are many research studies about the characteristics of LWAC [1–4].

In recent years, the research and development in the field of LWAC have been focused especially on the achievement of high strength, workability and durability together with low density of final composite material. Nevertheless, this effort is followed by a lot of problems related to the design of the fresh mixture composition as well as to the design of the final structural member.

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The ever-increasing effort of improvement of the LWAC characteristics leads to detailed research of the interfacial transition zone which is influenced especially by the pore structure of the aggregate [5,6].

2. The aim of experimental works

The investigation of the influence of the porous aggregate pre-saturation on the freeze–thaw resistance was the main aim of the experimental part. The results are introduced especially by the fracture parameters which are represented by the fracture toughness and fracture energy.

The experimental part deals with the three-point bend (3BP) test especially with the recording of the load–deflection diagram of the notched beam which is used for the evaluation of the fracture parameters value. For detailed description of the structural changes caused by the freeze–thaw cycles the compressive and splitting tensile strengths are investigated. The strength's parameters are determined on the specimen's fragments which are prepared from the broken specimens (after 3BP fracture test) by the cutting.

The lightweight concrete of the presumed strength class LC35/38 – D1.8 was used for the experiments.

3. Composition of light-weight concrete

Fresh concrete mixture was prepared from Liapor 4–8/600 light–weight expanded clay aggregate (year of delivery 2008), heavy-weight aggregate (DTK – Zaječí) of 0–4 mm fraction, CEM I 42.5 R cement, fly ash (Třinec), plasticizer (Sika Viscocrete 1035), stabilizing agent (Sika Control – 5 SVB) and water. The water, light–weight aggregate of 4–8 mm fraction, plasticizer, and stabilizing agent were dosed by volume, the remaining components by weight.

Three mixtures were made: LC1, LC2 and LC3; they differed only in the degree of the porous aggregate saturation at the moment of batching to the mixing device. The aggregate used in the "*LC1*" mixture was dried up to the steady-state in the oven plant. The *"LC3"* mixture contained the aggregate which was immersed in water up to achievement of 29% moisture (the aggregate was dried before the immersion). Finally, the "*LC2*" mixture contained the aggregate with the storage moisture of 13% (the aggregate was not conditioned for the batching at all).

The composition of the fresh concrete mixture is given in Table 1. The differences between mixtures are clarified in Table 2. Before the start of the design of mixture proportion, it is always very useful to verify the actual characteristics of the used porous aggregate. The basic physico-mechanical characteristics of Liapor aggregate are given in Table 3.

During the manufacturing of the test specimens, special attention was paid to compacting. The period and the method of compacting were designed with regard to the workability of fresh concrete that was determined according to the European guidelines for SCC [7].

All test specimens were stored in the same curing conditions. Immediately after demoulding they were stored in vessels with the temperature 20°C and RH ≥ 95% for 7 days. After that the specimens were removed from vessels and air-stored in the laboratory until the testing time occurred. The freeze–thaw test started after the testing specimens achieved age of 28 days.

Table 1. General mixture proportion of lightweight concrete

Components	Units	Quantities per 1 m^3
Liapor 4–8/600	m^3	0.36
DTK 0–4 mm Zaječí	kg/m^3	700
Cement 42.5 R	kg/m^3	440
Fly ash Třinec	kg/m^3	80
Sika Viscocrete 1035	kg/m^3	5
Sika Control – 5 SVB	l	1.6
Batching-water	l	180
Pre-wetting water	l	52

Table 2. Mixture details

	Units	LC1	LC2	LC3
Aggregate saturation	%	0	13	29
Pre-wetting water	l	52	37	0
Batching-water	l	180	179	184
Workability: T500/Slump-flow	s/mm	5.8/600	3.6/660	7.6/480
Class	–	VS2/SF1	VS2/SF2	VS2/–

Table 3. Physico-mechanical properties of Liapor aggregate

Liapor 4–8 /600	Units	Value
Loose bulk density	kg/m^3	615
Compacted bulk density	kg/m^3	637
Particle density (24 h)	kg/m^3	1026
Crushing resistance	N/mm^2	6.0
Mass absorption – 5 min	%	10.5
Mass absorption – 30 min	%	13.6
Mass absorption – 24 hours	%	21.2
Mass absorption – 7 days	%	25.2
Mass absorption – 21 days	%	31.1
Mass absorption – 56 days	%	40.5

4. Freeze–thaw test

The cyclical freezing and thawing of the saturated concrete specimens is the basic testing method for determination of the concrete freeze–thaw resistance [8].

According to the Czech standard the basic results of this test are especially mass decreases, bending strengths, compressive strengths on the prism's fragments, coefficient of freeze–thaw resistance and changes of monitored parameters measured with dynamic non-destructive testing method in the particular periods. These parameters are mainly used for determination of the rate of the internal structural damage.

In recent years the fracture parameters have been used for quantification of the material brittleness. This characteristic completes above-mentioned parameters very well.

For the experimental analysis two sets of prismatic specimens were used. The first set was exposed to the cyclical freezing and thawing (4 hours freezing and 2 hours thawing). The second set was not frost-attacked (specimens were air and water cured only).

Each set contained three different type of LWAC – "LC1" (mixture contained dried aggregate), "LC2" (mixture contained aggregate with the storage moisture of 13%) and "LC3" (mixture contained 29% saturated aggregate). The total number of testing specimens was 18 beams with dimension of 100×100×400 mm, each set contained 9 beams that means each set contained 3 beams manufactured from each mixture.

Both sets were tested in the same age after the first set achieved 200 freeze–thaw cycles.

The first set of the testing specimens was stored in the automatic freezing plant KD-20 which holds the temperature at –20 ± 2°C during the freezing period and at 20°C during the thawing period (Fig. 1.). For the second set special curing conditions were described. All specimens were air-stored in the laboratory. Each week, after every 25 freeze–thaw cycles, the specimens were immersed in the water bath for 50 hours.

These conditions conform to the conditions in the freezing plant during the 25 freeze–thaw cycles. The curing conditions of the second set followed above prescribed instructions during whole time of the freeze–thaw test.

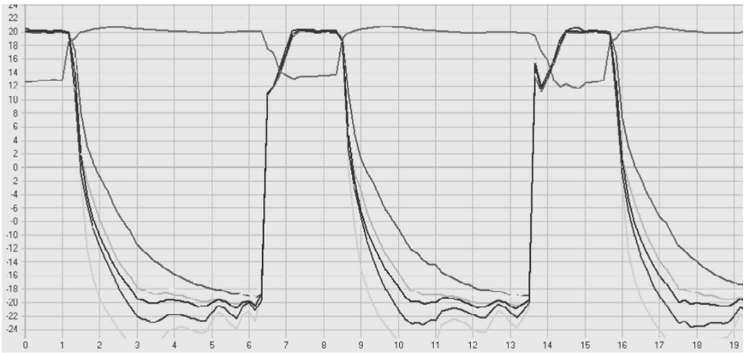


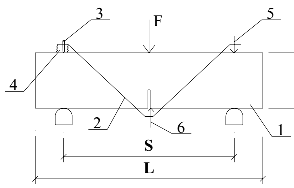
Fig. 1. Temperature during the freeze–thaw test versus time (temperature in °C – vertical axis; time in hours – horizontal axis).

5. Testing methods

5.1. Fracture test measurements

The experimental data are carried out from the 3PB fracture tests. Fig. 2. shows the arrangement of tested specimens. The 3PB specimen dimensions were L=400, S=300, W=100 and thickness=100 – in mm. The initial notch was made by a diamond saw that fabricated the 2–2.5 mm wide notches with controlled notch profiles and orientation. In this way specimens with notch length to width ratio of about 0.33 were produced.

During tests a load–deflection diagram was recorded. Modulus of elasticity values are obtained from the first/linear part of diagrams. Effective fracture toughness was measured using the Effective Crack Model [11], which combines linear elastic fracture mechanics and the crack length approach. An estimation of fracture energy value according to the RILEM method was calculated using work of fracture value [12].



1 – Testing specimen
2 – Metal Frame structure of deflectometer
3 – Deflectometer
4 – Elastic washer
5 – Two adjusting screw located above the support
6 – One adjusting screw located in the middle of the spam

Fig. 2. Arrangement of fracture test.

5.2. Strength characteristics measurements

The testing specimens for the strength tests were prepared after the fracture tests. The strength's parameters were determined on the specimen's fragments which were prepared from the broken specimens after 3BP test. From each broken beam with dimension of 100×100×400 mm two test specimens with dimension of 100×100×100 mm were cut. One specimen from each beam was used for determination of the compressive strength and the second one was used for determination of the splitting tensile strength value.

The compressive strength test was performed according to the Czech standard ČSN EN 12 390-3 [9], the loading rate was 0.5 MPa/s. The splitting tensile strength test was performed according to the Czech standard ČSN EN 12 390-6 [10], the loading rate was 0.1 MPa/s.

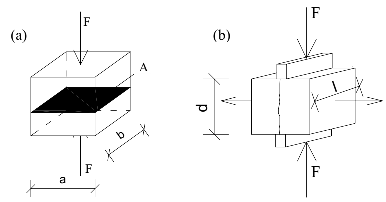


Fig. 3. Compressive strength (a); splitting tensile strength (b).

6. Results of performed tests

Selected results of the strength and fracture tests are given in the following figures. Mean values and standard deviations for the particular sets of the investigated parameters are presented: compressive and splitting tensile strengths are given in Fig. 4., modulus of elasticity is given in Fig. 5. And finally, fracture toughness and fracture energy are given in Fig. 6.

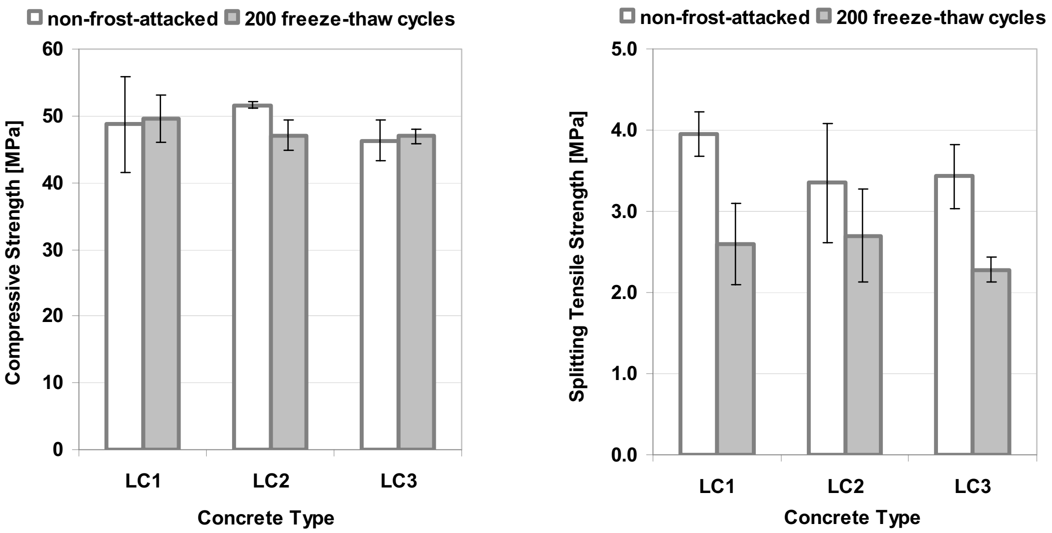


Fig. 4. Compressive strength: mean values ± standard deviation (left); splitting tensile strength: Mean values ± standard deviation (right).

7. Conclusions

Before the conclusion is made it is necessary to emphasize that the above presented results are only one part of the relatively extensive research and the obtained results will be used as a basis for the next research works.

Further it is important to remind that the testing sets contained a small number of testing specimens – only three specimens made from each mixture and that is why the obtained results cannot be generalized.

These conclusions reflect the observations made during the testing process, but do not explain exactly the mechanisms behind these observations.

Based on the performed experiments, the following conclusions may be drawn:

- During the freeze–thaw test it was proved that all three tested types of concrete mixtures are resistant enough from the mechanical damage of the specimen's surface point of view.

- There were also not observed any opened cracks on the specimen's surface after 200 freeze–thaw cycles.

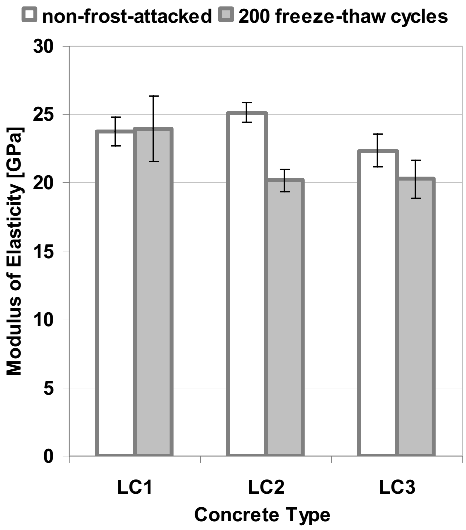


Fig. 5. Modulus of elasticity: mean values ± standard deviation.

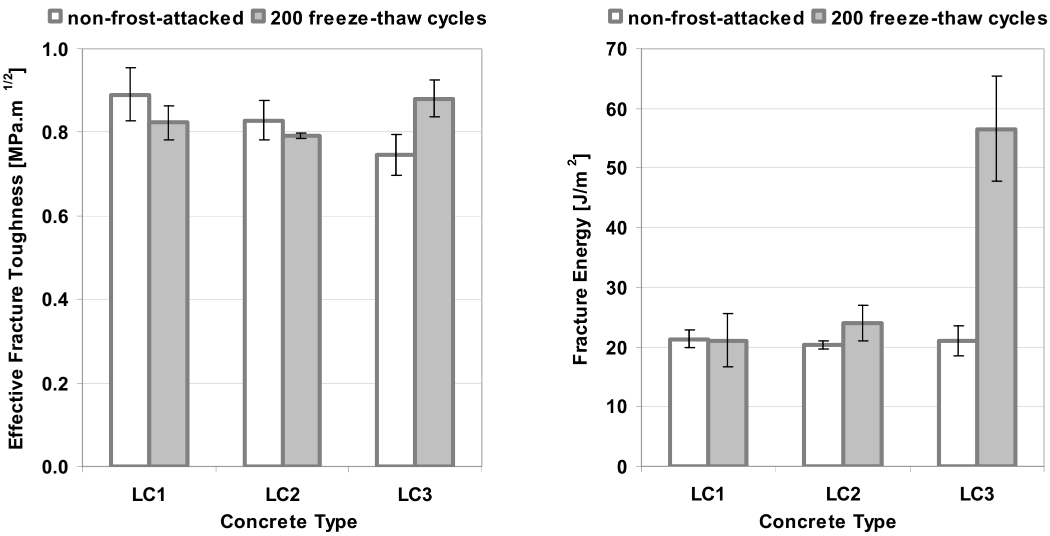


Fig. 6. Effective fracture toughness: mean values ± standard deviation (left); fracture energy: mean values ± standard deviation (right).

The analysis of variance (ANOVA) was used for the evaluation of the freeze–thaw cycles influence on the obtained fracture and strength parameters. Frozen and non-frozen sets of the test specimens were compared separately for mixtures LC1, LC2 and LC3. The test was performed on the significance level of 95%. Pursuant to the analysis results following statements for the particular mixtures may be stated:

- Mixture LC1 (mixture contained dried aggregate): There *were not found* statistically significant *differences* between frost and not frost attacked specimens *in the value of the compressive strength, modulus of elasticity, effective fracture toughness and fracture energy*. Nevertheless, it can be stated that the freeze–thaw cycles *negatively influenced* the value of the *splitting tensile strength*.
- Mixture LC2 (mixture contained aggregate with the storage moisture of 13%): There *were not found* statistically significant *differences* between frost and not frost attacked specimens *in the value of the splitting tensile strength, effective fracture toughness and fracture energy*. Nevertheless, it can be stated that the freeze–thaw cycles *negatively influenced* the value of *compressive strength and modulus of elasticity*.
- Mixture LC3 (mixture contained 29% saturated aggregate): There *were not found* statistically significant *differences* between frost and not frost attacked specimens *in the value of the compressive strength and modulus of elasticity*. Nevertheless, it can be stated that the freeze–thaw cycles *negatively influenced* the value of the *splitting tensile strength* and on the contrary the freeze–thaw cycles *positively influenced* the value of *effective fracture toughness and fracture energy*.

Freeze–thaw resistance is one of the many parameters which are related to the concrete durability. The durability of the LWAC is a relatively complicated problem because of the existence of many factors which are related especially to the LWAC mixture design (e.g. amount and type of fine particles, water to cement ratio, type of the porous aggregate, etc.) and to the curing condition. In cases of incorrect design of the LWAC mixtures, e.g. combination of the low *w/c* ratio and the dried porous aggregate may cause that the aggregate absorbs the effective water which is needed for hydration of the cement paste. This fact leads to the cracks origin and development which results in decrease in the concrete quality. On the other hand it must be also highlighted that the full-saturated aggregate may result, in some cases, in the weakening of the interfacial transition zone – the surface and subsurface pores are not accessible to the cement paste. This fact may also lead to a decrease in some strength or durability characteristics.

It can be said that the choice of the method of the porous aggregate conditioning (pre-saturation) has an essential influence on the final strength and durability characteristics of the LWAC because the various sizes and amount of the pores are filled in with water during the pre-saturation process.

One of the approaches to the examination of the factors including its risks, affecting the process of the LWAC behavior, is the usage of the mathematical model based on fuzzy sets [13].

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